# Advancements in Aeronautics Measurement System Characterizations


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# NASA's Aeronautics Test Program (ATP) is a model program created to preserve the capabilities of the largest, most versatile, and *comprehensive* set of testing facilities in the nation.

With NASA facilities located at the Ames Research Center (ARC) in Mountain View, California, the Glenn Research Center (GRC) in Cleveland, Ohio, and the Langley Research Center (LaRC) in Hampton, Virginia, the ATP offers government, corporations, and institutions a wide range of experimental test services that reflect 60 years of unmatched aerospace test history. The ATP maintains a nationwide team of highly trained and certified staff, whose backgrounds and education encompass every aspect of aerospace testing and engineering.

*Regardless of the test requirements, NASA's ATP can provide its clients with test results of unparalleled superiority.*

FACILITY SPECIFICATIONS

| | Speed | Reynolds number, per foot |
|---|---|---|
| 11-Foot Transonic Unitary Plan Facility | 0.20 to 1.45 Mach | 0.30 to $9.6 \times 10^6$ |
| National Transonic Facility | 0.1 to 1.2 Mach | 4 to $146 \times 10^6$ |
| Transonic Dynamics Tunnel | 0.1 to 1.2 Mach | 0.30 to $3 \times 10^6$ and 0.2 to $10 \times 10^6$ |
| 8-Foot High-Temperature Tunnel | 4, 5, and 7 Mach | 0.30 to $5.1 \times 10^6$ |
| 9- by 15-Foot Low-Speed Wind Tunnel | 0 to 0.20 Mach | 0 to $1.4 \times 10^6$ |
| 14- by 22-Foot Subsonic Tunnel | 0 to 0.3 Mach | 0 to $2.1 \times 10^6$ |
| 20-Foot Vertical Spin Tunnel | 0 to 85 ft/s | 0 to $0.15 \times 10^6$ |
| 4-Foot Supersonic Unitary Plan Wind Tunnel | 1.5 to 2.9 and 2.3 to 4.6 Mach | 0.5 to $6 \times 10^6$ and 0.5 to $11 \times 10^6$ |
| Icing Research Tunnel | 50 to 395 mph | — |
| 10- by 10-Foot Supersonic Wind Tunnel | 0 to 0.4 and 2.0 to 3.5 Mach | 0.1 to $3.4 \times 10^6$ (closed-loop) and 2.1 to $2.7 \times 10^6$ (open-loop) |
| Aerothermodynamics Laboratory | 6 and 10 Mach | 0.05 to $0.7 \times 10^6$, 0.2 to $2.2 \times 10^6$, and 0.5 to $8.0 \times 10^6$ |
| 8- by 6-Foot Supersonic Wind Tunnel | 0.25 to 2.0 and 0.0 to 0.1 Mach | 1.7 to $4.8 \times 10^6$ |
| 9- by 7-Foot Supersonic Wind Tunnel | 1.55 to 2.55 Mach | 0.50 to $5.7 \times 10^6$ |

**The goals of the ATP include:**

- **increasing the probability of having the right capabilities in place at the right time**
- **operating facilities in the most effective and efficient manner possible**
- **to foster those capabilities through a corporate management philosophy**
- **ensuring intelligent investment and divestment while sustaining core capabilities**

- **Providing quality data (information) to answer key technical research and development questions**

# *Test Technology – Instrumentation*

## *Critical Element of Data Quality*

**Force and angle-of-attack measurement technology are *key aeronautical capabilities* addressed by the National Aeronautics R&D Policy**

- **"We will dedicate ourselves to the mastery and intellectual stewardship of the core competencies of Aeronautics", and "key aeronautical capabilities"**
- **Capability in these technologies are not ones that NASA can readily purchase - the instruments are complex and require an experience based competency**

# *ATP Established Test Technology Capability Projects*

- **Establish a national test technology capability to support aeronautics test requirements for NASA, AEDC, and the nation**

- **Dedicate a few NASA engineers and technicians**
  - **Develop subject matter experts (SMEs) through *"hands-on" experience***
- **Centers/Programs cooperate to provide & fund FTE**
- **ATP/SCAP invest in maintenance and recapitalization projects**

# *Infusing Statistical Thinking*

- **Developed strategic technical goals – One goal is to:**

- **Improve calibration/characterization and develop recommended practices – multi-component force and angle measurement systems lack traceable calibration system standards**

  - **Train SMEs on methodologies, tools and techniques**
  - **Bring statistical engineers into work hands-on projects to facilitate the training and improve knowledge transfer**

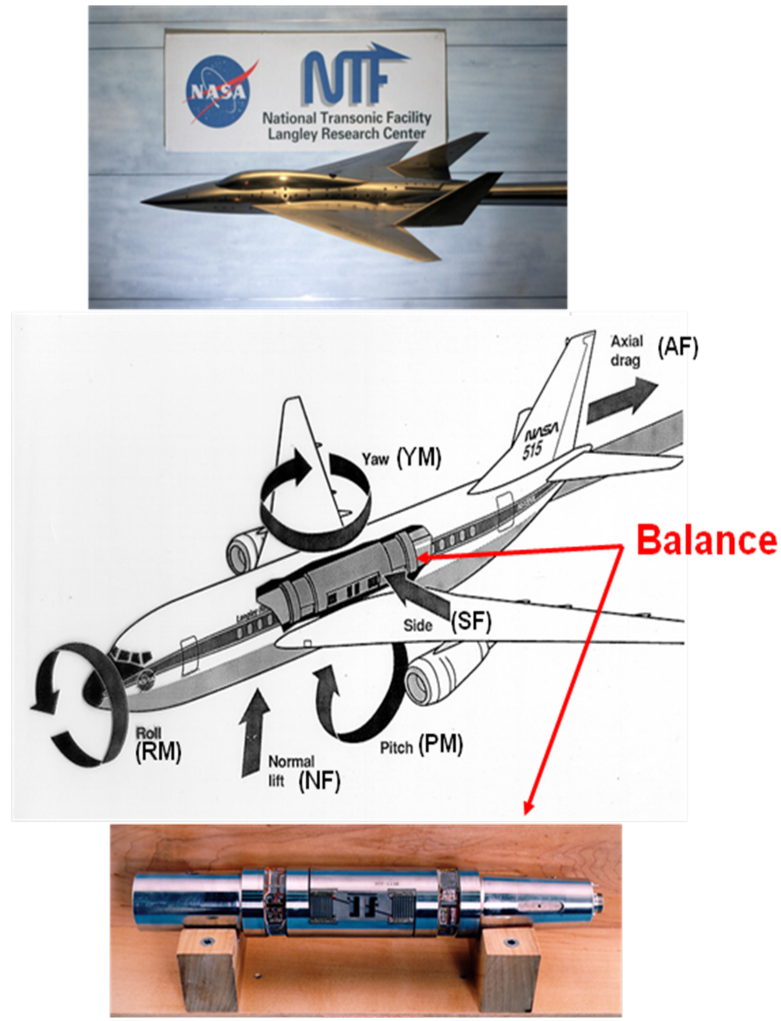
  - **Key: Continue questioning "WHY" – from the calibration systems to the experimental calibration designs to the calibration data analysis and model building**

**Calibration Goal:** *Produce an accurate mathematical model (matrix) to estimate the aerodynamic parameters from measured responses.*

# *Force Measurement*

## *Wind Tunnel Force Balances*

- **Specialized force measurement instruments utilized in >90% of wind tunnel experiments**
- **Measure six components of load**
- **Highly stressed**
- **Failure is potentially catastrophic**



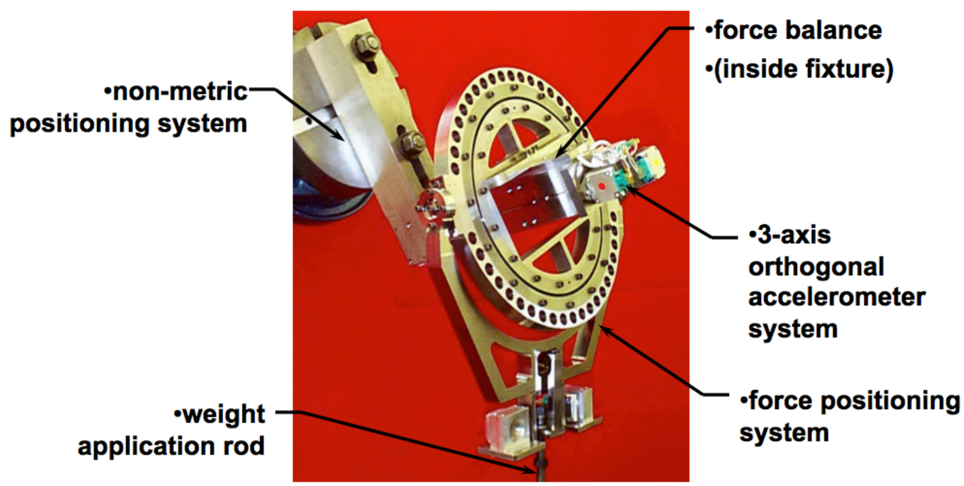
# *Wind Tunnel Force Balances*

BalFit Software Tool

- **Calibration/Characterization Improvements**
  - **Implementation of statistical analysis techniques tailored for balances**
  - **Model building based on:**
    - **Statistical significance**
    - **Variance inflation**
  - **Results:**
    - **Improved models (more robust)**
    - **New information on uncertainty intervals**
    - **Insight into instrument behavior and calibration experiments**

# *Wind Tunnel Force Balances*

- Calibration/Characterization Improvements
  - Implementation of the Single Vector System (SVS) as a standard technique
    - Integrates a Unique Force Application with DOE – Advantage of SME and Statistical Engineering collaboration (coupled experiment design and analysis into the calibration system development)
    - Randomization: to defend against systematic errors due to time, temperature or order of loading; Blocking: to prevent variation between blocks by breaking the experiment into manageable pieces; Replication: to cancel out random error and estimate pure error
  - Results:
    - Increased Accuracy, and 10x Reduction in Time and Cost
    - Fewer sources of systematic error
    - Insight into instrument behavior and calibration experiments

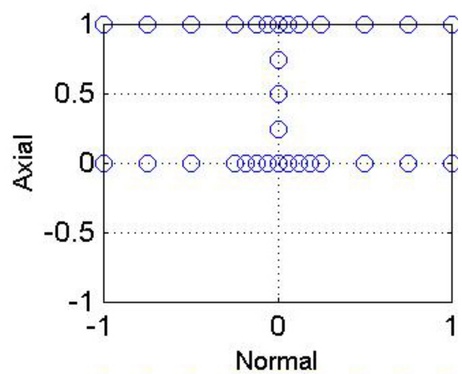


# *Wind Tunnel Force Balances*

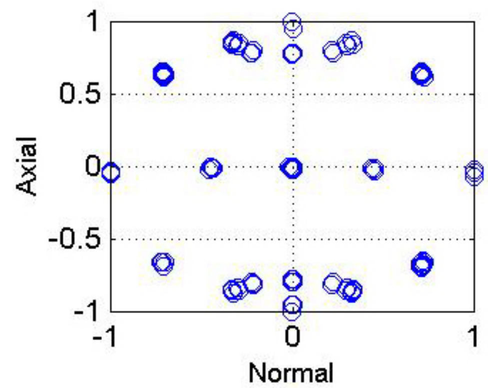
- **Calibration/Characterization Improvements**
  - **Implementation of design of experiments (DOE) techniques to more and complex calibrations**
  - **Adding additional factors such as temperature and pressure**

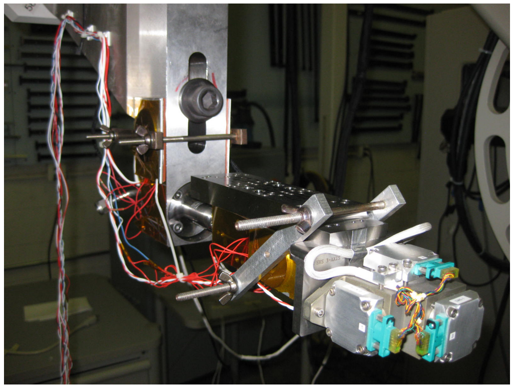
  - **Results:**
    - **Improved models (more robust)**
    - **More efficient experimental plans (number of runs)**
    - **Simpler implementation (more reasonable)**

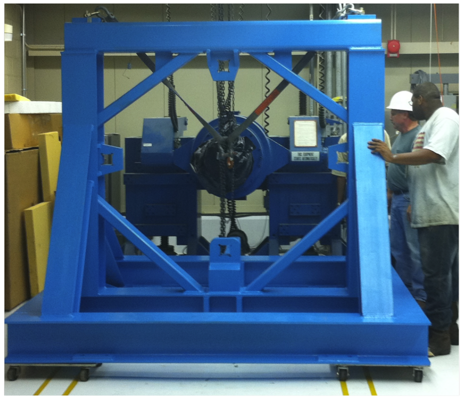
**OFAT design**




**DOE design**

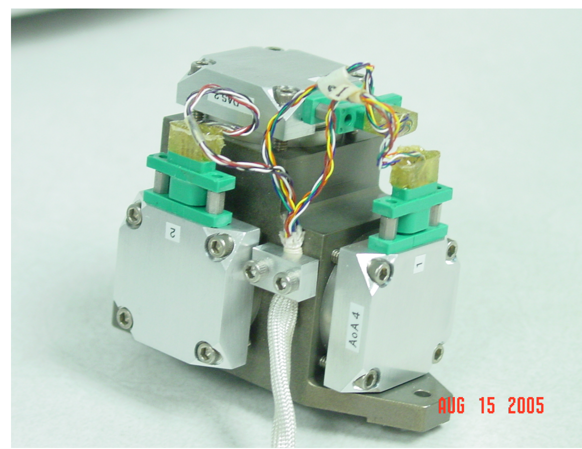




# *Angle Measurement Systems*

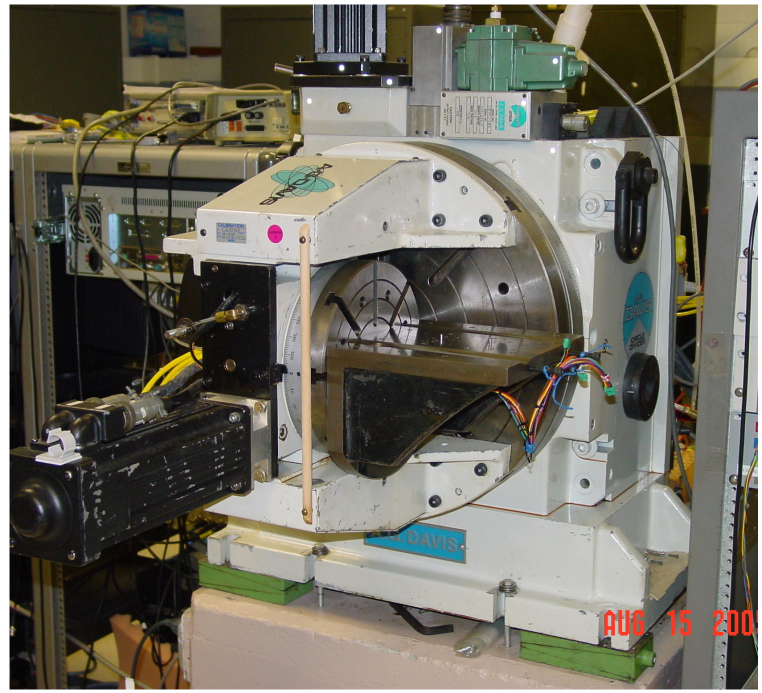
- **Angle Measurement System (AMS)**
  - **Utilized to determine the model orientation (Pitch and Roll)**
  - Three single-axis servo accelerometers (quartz flexures, Q-flex) mounted in a (near) orthogonal frame
  - Signal is proportional in magnitude and direction relative to earth's gravity vector
    - linearly proportional to the gravitational components
    - angle is proportional to the sine of the gravitational component


Tri-axial accelerometer (AMS)

# *Angle Measurement Systems*

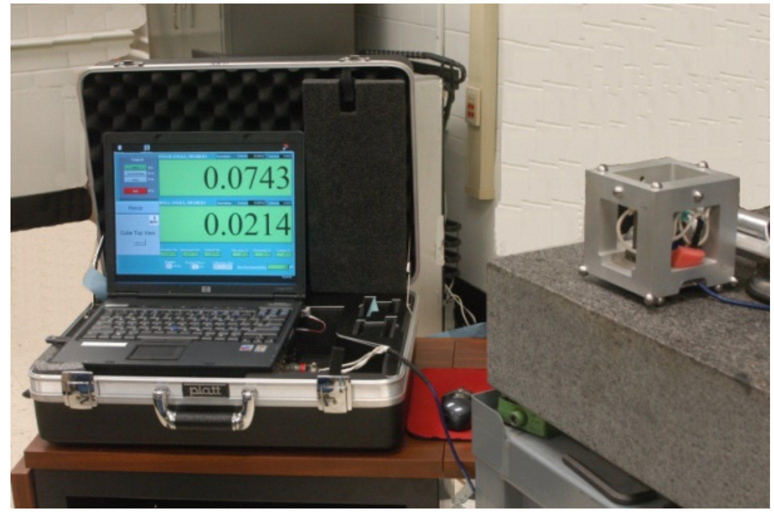
- **Calibration/Characterization Improvements**
  - **Implementation of statistical design and analysis techniques for baseline calibration**
  - **Model building based on:**
    - **Statistical significance**
    - **Variance inflation**
  - **Results:**
    - **Improved models (more robust)**
    - **New information on uncertainty intervals**
    - **Insight into instrument behavior and calibration experiments**

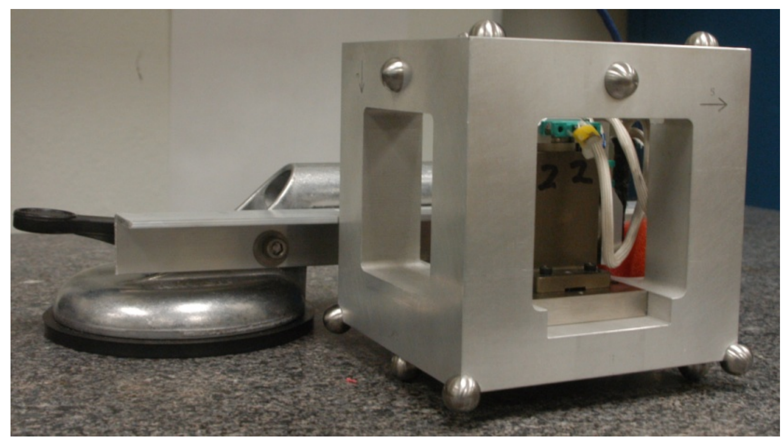



Baseline Calibration System

# *Angle Measurement Systems*

- Calibration/Characterization Improvements
  - Developed new calibration verification system – "Cube"
    - Adds statistical quality control
  - Results:
    - On-site, pre-test system performance verification
    - New information on uncertainty intervals
    - Insight into instrument behavior and calibration intervals



# *Summary - Infusing Statistical Thinking*

- **Developed strategic technical goals – One goal is to:**

- **Improve calibration/characterization and develop recommended practices – multi-component force and angle measurement systems lack traceable calibration system standards**

  - **Train SMEs on methodologies, tools and techniques**
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  - **Key: Continue questioning "WHY" – from the calibration systems to the experimental calibration designs to the calibration data analysis and model building**

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